

Formation Damage due to Mass Transfer in the Layers under a Dynamic Impact

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Abstract

Studies have shown that the same mechanism is responsible for the accumulation of huge energy in reservoirs and inability to obtain inflow from potentially productive layer. Considering the process of chemical adsorption in layers, it managed to show that when the fluid flows into the reservoir, even moderate magnitudes of over balance internal electromagnetic radiation occur. Under the influence of this radiation, certain order of direction and intensity oscillations of phonons is set. Regard to borehole maximum intensity, oscillations of phonons will take place in the zone of high tangential stresses. Therefore, at some depth from the borehole, wall rock will be destroyed into particles commensurable with clay. Behind the transition layer due to throw of electromagnetic energy into the reservoir and fluid, mass transfer from the periphery of the reservoir to an extended zone with stepwise increased porosity and high thermodynamic compressibility of fluid is formed. Inside this zone a strong and long-range interaction between particles of fluid is developing. Throw in of electromagnetic energy is a result of intensive electromagnetic radiation due to the inflow into the reservoir mud or kill fluid. This formation is called the associate. The associate emits electromagnetic waves that change over allogenic particles in porous medium beyond the associate in the excited state. Between associate and excited particle strong interaction set in, which manifested in attraction of particle to the associate, and it becomes a full member of the associate. Thus, there is a selective implication of allogenic fluid particles into the associate.

Keywords

Chemical Adsorption; Electromagnetic Radiation; Phonon Oscillations; Thermodynamic Coefficient of Extensibility; Accumulated Energy; Rock Pressure; Explosion

Introduction

In many cases, a dynamic impact on the layers is accompanied by mass transfer of reservoir fluids such as water, oil or gas. The dynamic impact on the stratum starts with the first meters of drilling and lasts throughout "life" of wells. Formation exposing with firing guns, increasing the density of perforations,

expansion the filter zone, or connection previously nonperforated objects to the working intervals - all these actions are associated with short term intensive impulsive stresses on layers. That all kinds of intensification works of injectivity of injectors and productivity of producers using pulsed - wave technologies should be added.

Mass transfer in the reservoir can be initiated by seismic load of drilling process and start long before entry of drilling tool into this layer. Subsequently recorded during the opening-up of reservoirs water-oil and gas shows or lost returns connect with local natural areas of abnormally high (AHRP) or abnormally low reservoir pressure (ALRP). Without denying existence of such anomalies in nature is still possible to say that in majority of cases petroleum experts deal with the layers which have undergone technological transformations based on mass transfer of reservoir fluid from the periphery to the well or in the opposite direction as a result of seismic load initiated by drilling.

Field case study

From the experience of drilling first exploratory wells both in large and relatively small oil and gas fields, it follows that the mass transfer to the well caused by the drilling accompanied by the occurrence in the vicinity of borehole tremendous energy reserve. This energy can be enough for blow up most of the drill string. Not always energy accumulated in the reservoir is released during drilling, but it can be released when perforation carried out after landing and cementing casing string accompanied kill mud discharge and transition to the unauthorized blowout as it happened on the Bulamar gas-condensate field (Azerbaijan), a number of prospecting and exploration wells of Hapchagaysky megalithic bank and other regions of the Russian Federation. If the supply of energy in the vicinity of borehole is not so great after short term

open hole formation test, it can create the illusion of finding a large deposit of hydrocarbons.

Another extreme reaction to the seismic load during drilling is leaving formation fluid from the borehole wall into the interior of the reservoir. When drilling in mid- and low-permeability reservoir formation, fluid can move away from the well for tens of meters. The process cannot be explained by a simple mud filtrate-reservoir fluid displacement and requires detailed investigation.

Both accumulation of energy in the wellbore zone and withdrawal reservoir fluid from the borehole wall complicate or even make it impossible to obtain inflow from the reservoir.

Table 1 summarizes the results of perforation and cased hole formation tests on the exploration areas of the Hapchagaysky megalithic bank (northeastern Siberia). In the course of drilling wells and selective open hole formation tests, following information about formations was obtained: character of saturation and potential productivity. Bearing capacity of the reservoir rock depending on the effective pressure (difference between rock and reservoir pressure) and character of saturation has not been established. Formation tests after the completion of wells and opening-up with cumulative perforators did not provide hydrodynamic connectivity between downhole and reservoir. Additional mud-acid treatments were ineffective.

Upon the recommendation of the author of this article cased hole formation tests have been repeated after a sufficiently long period of passive idleness. The idea was implemented on the exploratory wells in which potentially productive layers were characterized by unclear character of saturation and sharp decrease in temperature after drilling. For integrity of the experiment, the same schedule-size of the cumulative perforator was used. During the experimental-industrial works, particular attention was paid to the presence at least a weak hydrodynamic connection between gas reservoir and well after the first stage of perforation. Because of presence such connection wellhead pressure could increase as a result of gravitational displacement liquid to gas. However, during the whole period of observation, the appearance of gas at the wellhead was not observed. The following conclusions could be drawn. Firstly, violation by drilling the steady metastable state in the formation has led to behaviour in the reservoir complicated process, which resulted in the layer, got

entirely new physical and mechanical properties. Secondly, cumulative perforator shot into the formation with altered physical and mechanical properties is not able to create channels having even low-bandwidth under the action of rock pressure. Thirdly, temperature of the reservoir is reduced and the diffusion of gas to the borehole wall increases supporting strength of the reservoir. In this case, reperforation made in a completely different reservoir properties and new perforation channels provide a hydrodynamic connection between well and layer.

TABLE 1 INFLUENCE ON THE EFFICIENCY OF PERFORATION PASSIVE IDLENESS DURATION OF THE WELLS

Region; Well	Interval, m	Test Result	Passive Idleness Duration, Months	Choke Diameter, mm	Test Result After Passive Idleness Duration, 10 ³ m ³ /d
Middle Tyung; 231	3424,8 – 3439,1	no inflow	2	12 mm	80
Peleduyskaya; 751	1549,0 – 1557,0	no inflow	12	10 mm	120
Hotogo- Murbayskaya; 730	2016,4 – 2021,6	no inflow	5	10 mm	135
Mid- Botuobinskaya; 403	1897,6 – 1900,0	no inflow	5	10 mm	120

Theoretical foundations

Despite of particular importance on the consequences of fluids mass transfer for efficiency and environmental safety of prospecting and exploration hydrocarbons, up to the present time, there are no theoretical foundations of mass transfer in the layers under a dynamic impact.

Mass transfer of the fluid in porous media can be considered only in conjunction with the processes in the minerals and their physical properties. Contact of any fluid with the surface of minerals is accompanied by adsorption. There are two types of adsorption: physical and chemical. The distinction between physical and chemical adsorption consists primarily in difference of the forces that hold adsorbed molecule on a solid surface. Forces of electrostatic origin such as the Van der Waals forces, electrostatic polarization

forces and electrical image forces are responsible for physical adsorption. If acting forces are of chemical nature (exchange forces) then such adsorption is called chemical. In this case, adsorption is a chemical compound of the fluid molecule with the solid. Binding energy of the adsorbed fluid molecule with the solid surface in case of physical adsorption is 0.01 eV and only in rare cases can reach 0.1 eV.

Binding energy of chemical adsorption can reach and even exceed 1 eV. Certainly it is not only the difference in magnitudes of the binding energy, but also a fundamental difference between the approaches to consider the interaction of adsorbed molecules with the solid surface and among themselves.

In the case of physical adsorption, system of adsorbed particles fairly interpreted as a two-dimensional gas covering a solid surface. Influence of the adsorbent on the adsorbate is considered as a weak disturbance. Therefore do not expect significant changes in the interaction between adsorbent and adsorbate in case of shear under the action of the pressure gradient.

Situation is different for the chemical adsorption. In this case the adsorbed particles and lattice of adsorbent form a single quantum mechanical system. At the same time, the chemisorbed particles become active participants in the electronic sector of the lattice. In these conditions, the chemisorbed particles are limited in its motion because when moving along the surface, they can to overcome only those energy barriers that do not exceed the binding energy of the particle with lattice of the adsorbent. Large defects and grain boundaries turn out an insurmountable obstacle for them. Shear chemisorbed layer of particles on such defects under an external pressure gradient will break of chemical bonds. The more chemisorbed particles involve in the movement, the greater number of simultaneous breaks of bonds occur. Actually this makes fluid filtration processes close to rocks destruction processes. But the destruction of rocks is associated with electromagnetic radiation, which is recorded through the presence of "windows" in the thickness of the rocks ¹. Under the "window", it should be understood that the area of the reservoir in which electromagnetic waves propagate with very low attenuation.

Based on this, it can be argued that the filtration of fluids in reservoirs characterized by chemisorption will be accompanied by internal electromagnetic radiation, just as it occurs in the destruction of the

rocks. This electromagnetic radiation from individual acts of breaking the chemical bonds will not represent interest before the moment of coordination all electromagnetic fluctuations in the area of the current drainage and forming a "window" that extends along the zone of filtration and several orders of greater magnitude than the size of this zone. The chemisorbed particles which gain preferential thermal phase oscillations coinciding with the direction of filtration will also take part in forming a "window". At relatively weak interaction between individual particles of filterable fluid and limited filtration rates, which corresponds to a low-intensity radiation, the effect of fluid ultramobility can be obtained. In case of liquidation external pressure gradient, fluid filtration will continue until the dissolution of ordered thermal oscillations of the fluid particles. Duration of such inertial effect can last for many hours. Sufficiently high intensity of radiation (high filtration rates) will lead to increase in the interaction between particles and enhance fluid compressibility. Final result of the process can turn out to be obliteration ^{4,5} and disappearance of fluid ultramobility with the impossibility of repetition.

Furthermore, the reaction of minerals to electromagnetic radiation accompanying the filtration of fluids is considered. From the position of quantum theory, any load on a mineral should be compensated by pulses of phonons (associated lattice oscillations). Electromagnetic radiation can provide in-phase coupled oscillations of the lattice within a single mineral, and contribute to the intensity those oscillations which are directed along the lines of maximum stress. Considering the process of chemical adsorption in layers, it managed to show that when the fluid flows into the reservoir, even for moderate magnitudes of over balance ($\Delta P_R \geq 2MPa$), electromagnetic radiation occurs (which is not contrary to the fundamental law of electrodynamics: accelerated motion of charged particle generates electromagnetic radiation). This refers to the internal radiation because it occurs inside the porous medium. Under the influence of this radiation, a certain order of direction and intensity oscillations of phonons are set (associated lattice oscillations in quantum representation), corresponding to reduction of external forces acting on the rock minerals. Regard to borehole maximum intensity, oscillations of phonons will take place in the zone of high tangential stresses, i.e. directly in the layers adjacent to the borehole wall.

Experimental procedure

To verify theoretical provisions, high-pressure system has been designed and constructed by the author, in which artificial and natural cores samples length of 150-200 mm and 90 mm in diameter can be loaded by axial and lateral pressures in a special core holder² up to a magnitude 80 - 100 MPa. In turn core holder with sample was placed in high pressure vessel (HPV) and in pore volume, initial filtration characteristics of the sample for nitrogen and kerosene were evaluated. Scheme of setup is given in Fig. 1. Core samples of natural rocks mentioned dimensions were drilled out from Grozny outcrops of oil- and gas-saturated sandstones. A number of investigations have been conducted using cores sampled from the Neocomian and Jurassic sediments of Western Siberia, represented by sandstones with clayey and carbonate cement. Artificial core samples were a mixture of certain fraction quartz sand with a marshallitum and liquid glass, compacted in a specific demountable forms and burnt gradually at temperatures of 300 °C, 500 °C, 800 °C and 850 °C. After final baking from the core faces to eliminate end effects slices length of 20 mm were cut. To compare the effect of different loads on the rock face of core sample directed to the vessel could be opened up to 85 percent or closed with steel disc having a hole along the axis of sample in diameter of 8-9 mm. The last case in the core drilled a hole with the same diameter and length of 70-90 mm. Scheme of sample preparation for installation it into the core holder is given in Fig. 2. To study the influence of rock properties on following effects of the fluid inflow into the formation through the flat face and the cylindrical wall of the channel, artificial core samples were used. These core samples were indicated emission of electrons (the luminescence) during multiple impacts of the indenter (samples of group A) and samples of group B are practically characterized by the lack of emissions³. For obtaining comparable conditions of dynamic loads on the layers during drilling and laboratory, studies in high pressure vessel were provided for demolition of small explosive charge.

All studied core samples before installing them into core holder were fully saturated 5-percent aqueous solution of NaCl. Further following operations were performed:

Step 1:

Installing the core in the core holder.

Step 2:

Explosive charge (1.5 g) attached to a breech-block of HPV within 25 - 30 cm from the face of the core was placed above the core holder.

Step 3:

Core holder with an explosive charge went down in HPV and the breech-block was closed.

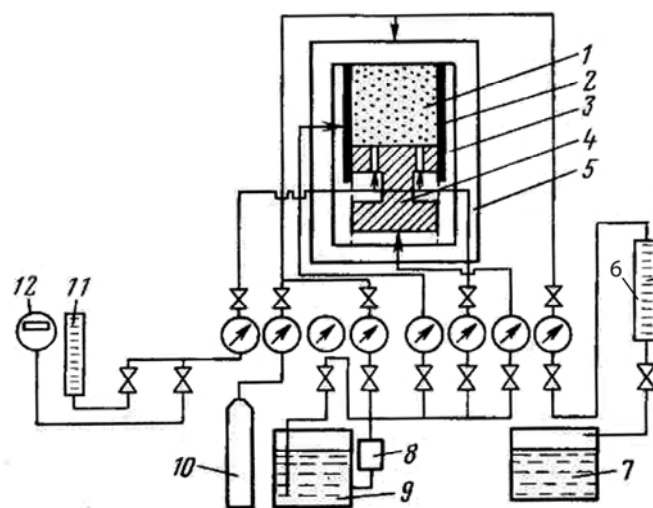


FIG. 1 THE SCHEME OF LABORATORY SETUP

1 — rock sample (core), 2 — rubber sleeve with a metal clip for the lateral hydraulic compression, 3 — casing of core holder, 4 — plunger for axial hydraulic compression and fluid filtration through it, 5 — high pressure vessel, 6, 11 — metering tanks, 7 — dump tank, 8 — high pressure hydropump, 9 — initial tank, 10 — gas vessel, 12 — gas meter.

Step 4:

HPV was filled with kerosene and partial displacement of water from the core with kerosene fixing the magnitude of the residual water was carried out.

Step 5:

Kerosene in HPV was replaced by clay mud and then face of core sample or the surface of drilled channel contacted with drilling mud.

Step 6:

The required over balance on saturated core ΔP_R was created simultaneously increased pressure in the drilling mud and in pore volume of the core. The magnitude of over balance varied in the range from 0 to 10-15 MPa.

Step 7:

After maintaining a constant over balance within an hour drilling mud was removed from HPV.

Step 8:

In the process of creating a drawdown ΔP_D during filtration of kerosene through the core the indicator diagram was recorded.

Step 9:

After fillup HPV with drilling mud and creating required magnitude of over balance demolition of explosive charge was carried out.

Step 10:

The drilling fluid was removed from HPV and drawdown was created.

Step 11:

During filtration of kerosene through the core sample the indicator diagram was recorded.

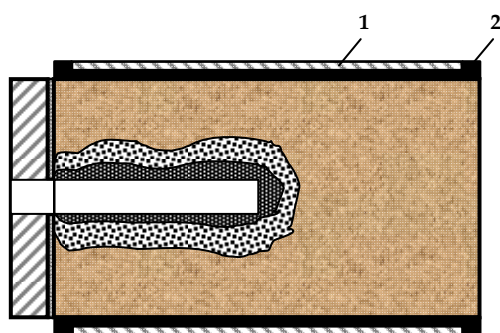


FIG. 2 THE SCHEME OF CORES GROUP A AND B WITH THE CHANNEL AND RUBBER SLEEVE WITH A METAL CLIP. IT IS SHOWN DESTRUCTION ZONE OF THE CHANNEL IN THE SAMPLE OF GROUP A

1- metal clip; 2 – rubber sleeve

The samples of group B did not change its permeability neither under long-term static clogging nor clogging combined with the explosive impact. On flat core, faces of the group B destruction of minerals weren't detected even at $(\Delta P_r \geq 15 \text{ MPa})$ and mass of the explosive charge 30 g. The results did not change when using core samples of group B with drilled channel and mass of explosive charge increased up to 30 g and the magnitude of over balance up to 15 MPa. Permeability and productivity index of channel managed to restore with reverse kerosene flow in terms of minimal drawdown. On flat core faces of the group A individual minerals of subsurface zone were subjected to destruction, regardless of the mass of explosive charges at overbalance $(\Delta P_r \geq 2 \text{ MPa})$. Zone of destruction and increased porosity in samples of the group A with a drilled channel at $(\Delta P_r \geq 2 \text{ MPa})$ are

shown in Fig. 2. Using samples of group A with drilled channel showed that combination of clogging at magnitude of over balance $(\Delta P_r \geq 2 \text{ MPa})$ with explosive impact was accompanied by a sharp decrease in productivity of the channel. Filtration when creating a reverse flow could be carried out only through the bottom of the drilled channel. Investigations after sealing bottom of the channel showed it. Fig. 3 shows the dependence on the magnitude of drawdown ΔP_d kerosene flow rate Q through the bottom of drilled core in the sample of group A and use for clogging with an explosion different liquids and suspensions. Filtration through the lateral surface of the channel was completely absent even at very high drawdown.

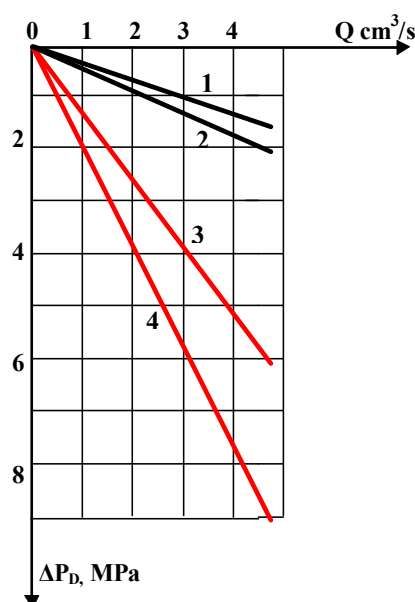


FIG.3 DEPENDENCE ON THE MAGNITUDE OF DRAWDOWN ΔP_D KEROSENE FLOW RATE Q THROUGH THE BOTTOM OF DRILLED CORE IN THE SAMPLE OF GROUP A. MINIMAL STATIC OF OVER BALANCE WAS 2 MPA

The composition of drilling mud:

1 - technical water; 2 - clay solution of 5% NaCl, 5% CaCl₂, 5% sulphite waste liquor (SWL); 3 - clay solution of 5% NaCl, 0,5% CaCl₂, 5% SWL; 4 - clay solution of 5% NaCl, 5% SWL

Analyzing the experimental results, it can be argued that around the channel at clogging, combined with explosive impact, there has been thrown into a porous medium energy in the form of electromagnetic radiation. In porous medium this radiation with multiple reemissions will persist long enough. In the presence of any recharge emitters with the same frequency, characteristics forming zone will not decay, but can also grow. New formation can be called the associate. Confirmation of the associate occurrence

and its properties is the strong magnetization of a metal clip, placing outside of rubber sleeve in core holder (Fig.2). Despite having made a complete demagnetization of clip before clogging with the explosion, it again is magnetized. Magnetization of clip is completely absent when using during explosive clogging samples of group B. Detailed investigations have shown that when trying to create in the associate gradient of pressure by external pressure, counterpressure on its boundary occurs. This counterpressure is equal to the magnitude of external pressure and focused in opposite direction. Thus, directed thermal oscillations of the particles in fluid create on the boundary impassable obstacles for penetration of external pressure into associate. In fact, the emergence of counterpressure at the associate boundary is similar to appearance of counterpressure at the boundary of the mineral loaded under any direction at the expense of codirectional oscillation of phonons. Therefore to displace water with kerosene from the zone around the channel was not possible both when creation of high drawdown and significant increase of pore pressure in the core.

The change of core's volume is investigated. To study the maximum strain core samples of the group A in radial direction at clogging with explosive impact, thin copper wire in a few turns was wound on the sample and the ends of wire were soldered. Fig. 4 shows the scheme of core with winded wire to determine

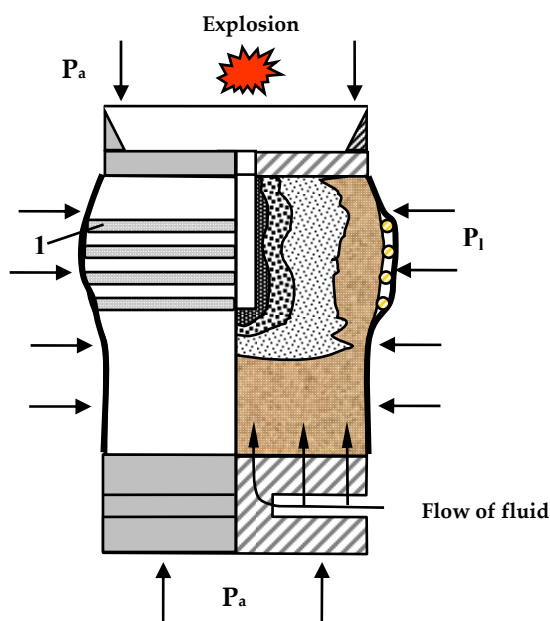


FIG. 4 CORE WITH WINDING OF THIN WIRE

P_a – axial pressure; P_l – lateral pressure;

1 – winding of wire

maximum radial strain. Knowing the initial and final length of the wire after the deformation associated with explosive clogging, it is easy to determine the maximum value of radial strain. In the experiments this value was about of 2 absolute percent at residual water saturation of 10%. Virtually all of the residual water moved into the zone of phase transition.

With the growth of core water saturation, maximum radial deformation of the sample also increased. So after the explosive impact at 30-40% of water saturation, maximum radial strain was 6 and more absolute percent, but the upper part of the core was completely destroyed in spite of very high value of hydraulic compression (50 - 80 MPa). Scheme of core destroying is given in Fig. 5.

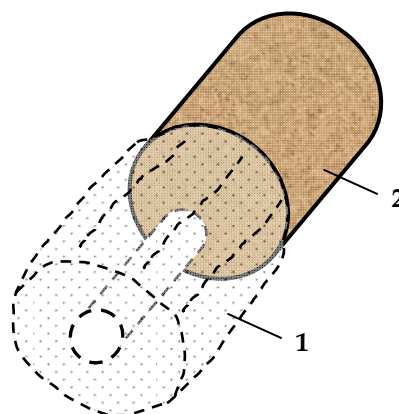


FIG. 5 DESTRUCTION OF CORE AROUND THE CHANNEL

1 – destroyed part of core; 2 – undamaged part of core

Using samples of group A, mass transfer in the core after the creation of associate was studied. For this purpose, evaluation of fluid mass transfer after the increase of pore volume in core samples of the group A was carried out in the following way. Upon completion of cake formation on the surface of drilled channel from the CMC-treated (1.5%) mud and creation of over balance magnitude 2 – 3 MPa, an explosive impact on the sample within the HPV was carried out. Moving in the core of water containing colloidal particles of SiO_2 was monitored using the Mariotte vessel located outside of HPV. The residual water saturation of the core was not more than 10% (taking into account the mud filtrate). Pipeline from the core holder was connected to the Mariotte vessel filled with tinted liquid to a level 0-0. Decrease or increase level of liquid in a transparent capillary after the explosion provided an indication of the direction fluid movement in the core. The scheme of the test bench is shown in Fig. 6. In samples of group A, liquid moves to the explosion despite a sufficiently large

magnitude of over balance ($\Delta P_R \geq 2MPa$) (Fig. 7). Air breaks through the bottom end of the capillary below the point L. One of the reasons of fluid movement to the explosion consists in increasing porosity of the sample during the formation of associate. However, the additional pore volume would be filled in a few seconds. At the same time the movement of fluid towards the explosion in the core continued for tens of minutes, which indicates that the volume of fluid in the core went to decrease and to complete the process required a lot of time (tens of minutes). By additional studies after extraction of core from laboratory setup, the absence of water in the core was detected.

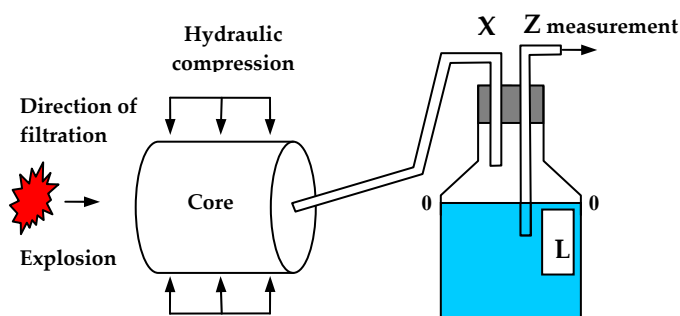


FIG. 6 SCHEME OF SETUP FOR DETECTION OF SMALL FLUID DISPLACEMENTS IN THE CORE. POINT L – THE LOWER LEVEL OF THE CAPILLARY Z

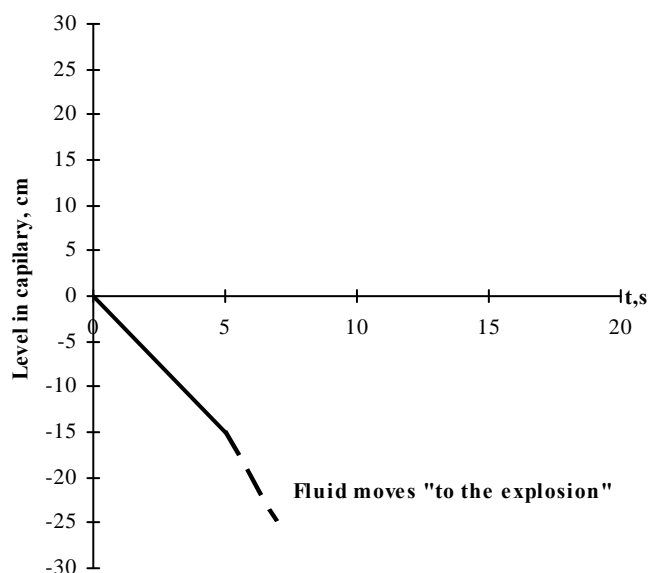


FIG. 7 DYNAMICS OF LIQUID LEVEL IN CAPILLARY AFTER THE EXPLOSION. SAMPLES OF GROUP A

Making use of scheme shown in Fig. 8. Appearance of associate led to an increase of porosity and compressibility of aqueous colloid. Mixture of kerosene and water, remaining outside the associate, will be subjected to electromagnetic radiation by

association in which between particles of the fluid, located in the energetically excited state, there are tremendous forces of gravity. Particles of aqueous colloid, located outside the associate, but in a porous medium, when excited by electromagnetic radiation of associate under the action of gravity, move towards the associate (Fig. 8a). This movement takes place with acceleration due to increase of the radiation intensity from the movement of the particles themselves. As a result, the particles become full members of the associate, bringing into it an additional electromagnetic radiation.

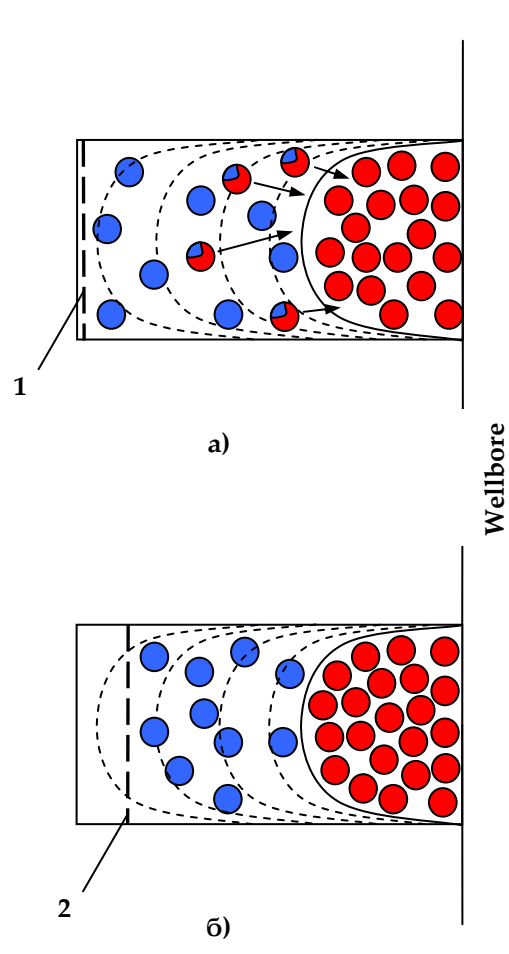


FIG. 8 SCHEME OF IMPLICATION OF EXCITED PARTICLES INTO THE ASSOCIATE: A) THE BEGINNING OF THE PROCESS B) THE LAST STAGE OF THE PROCESS

- - fluid particles in the excited state
- - particle of fluid excited by the associate
- - - - - electromagnetic radiation

1 - initial boundary of the fluid in the core of the group A

2 - the border after implication of the excited particles into the associate in the core of the group A

Fluid particles of otherwise origin are not excited at frequencies of electromagnetic radiation of the associate, and, being allogenic, don't interact with associate. Therefore all particles of aqueous colloid are implicated in the associate, and after a strong compression their volume decreases that leads to the release of volume in the core. It is schematically shown in Fig. 8b. Moving of fluid particles in the associate occurs quite slowly that was detected during the experiments. Thus, due to selective movement of particles of aqueous colloid into the associate, last-mentioned will increase a volume and store energy.

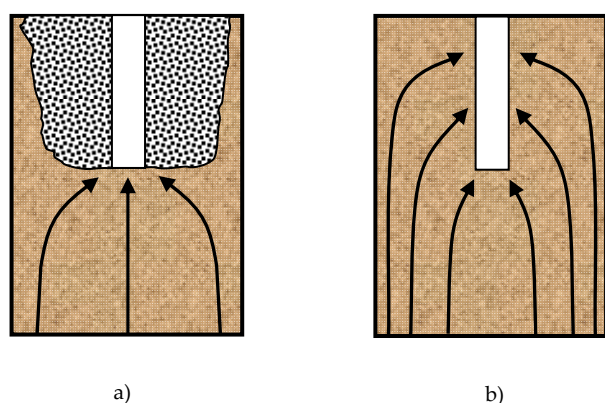


FIG. 9 SCHEME OF KEROSENE FILTRATION THROUGH THE SAMPLES OF GROUP A WITH THE CHANNEL AFTER FORMATION OF THE ASSOCIATE AROUND THE CHANNEL (A) AND AFTER A TEMPORARY DISCHARGE CORE FROM THE HYDRAULIC COMPRESSION AND RECOVERY OF HYDRAULIC COMPRESSION (B)

The associate in the core is stored for a long time (for many weeks) without recharging from external emitters, but, it is rapidly destroyed when unloading from the rock pressure (hydraulic compression). Fig. 9 shows the scheme of kerosene filtration after formation of the associate around the channel (Fig. 9a) and after a temporary discharge core from the hydraulic compression and recovery of hydraulic compression (Fig. 9b). Hence emerged metastable state in the reservoir can exist only at presence of rock pressure and, in a great measure, due to rock pressure.

Conclusions

During drilling or killing the well for repair works in a wellbore area of reservoir zones can be formed, where accumulation of energy because throwing into the reservoir electromagnetic energy and fluid mass transfer from the periphery of the reservoir to the wellbore takes place. Throwing into the reservoir of electromagnetic energy is a consequence of mud or kill

fluid inflow into the layer at high overbalance. This process can occur only in layers at low electronic work function to the surface of minerals.

Zones with accumulated energy are characterized by strong and distant interaction of particles between themselves and therefore the fluid in these zones has a high thermodynamic compressibility.

The associate is capable of growth and accumulation energy by implication into itself congenerous particles.

The associate is resistant and on the stage of development insensitive to external influences.

Based on laboratory and field studies, it can be argued that the associate can persist for months

During completion of energy accumulation, sensitivity of the associate against external influences sharply increases and even comparatively weak impulsive impact can result in release of enormous energy and the emergence of an ecological catastrophe.

The emergence of associate is impossible without the internal electromagnetic radiation generated by a filtration of fluids.

The associate creates impassable obstacles for fluid filtration and, therefore, complicates the process of prospecting, exploration and development of hydrocarbon deposits.

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Victor Zamakhaev earned his PhD degree in the field of physics of reservoir from Moscow Engineering and Physical Institute. For a long time he worked for All-Russian Scientific Research Design Institute of Explosive Geophysics where he was head of well completion and testing department.

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